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Published in:
I E E E Photonics Technology Letters

Link to article, DOI:
[10.1109/68.300165](https://doi.org/10.1109/68.300165)

Publication date:
1994

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Braagaard, C., Mikkelsen, B., Durhuus, T., & Stubkjær, K. (1994). Modelling the dynamics of wavelength tuning in DBR-lasers. *I E E E Photonics Technology Letters*, 6(6), 694-696. <https://doi.org/10.1109/68.300165>

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Modelling the Dynamics of Wavelength Tuning in DBR-Lasers

Carsten Braagaard, Benny Mikkelsen, Terji Durhuus and Kristian E. Stubkjaer

Abstract— To minimise the wavelength switching times, dynamic numerical investigations of the tunability of DBR-lasers are performed, taking the transient thermal behaviour into account. It is predicted that a decrease of the waveguide dimensions in the Bragg section reduces the switching times. Also a trade off between ultra fast wavelength switching and influence of thermally induced disturbance is established.

I. INTRODUCTION

WAVELENGTH tuneable light sources, such as DBR-lasers, are expected to be used in optical WDM-systems as transmitters, as local oscillators in coherent systems [1] and as tunable wavelength converters in connection with, e.g., optical space switching [2]. Besides the *tuning range*, that determines the maximum number of channels in the WDM-system, the *tuning speed* of the DBR-laser is of importance for some applications [3]. Therefore, devices with a large tuning range and minimal wavelength switching times are required.

It is known, that thermal effects introduce a critical limitation for the tunability of the DBR-laser, primarily because the temperature rise due to the injection of current leads to an increasing refractive index. Consequently, the maximum tuning range is reduced, and the thermal time constant in the range of μs leads to a slow drift in wavelength after a fast wavelength tuning has taken place.

The properties of wavelength tuning are investigated with emphasis on the wavelength switching times, using a numerical model that accounts for transient thermal effects. Calculations show, that high current injection leads to fast wavelength switching because of a short effective carrier lifetime in the tuning section. The large current injection does, however, also increase the influence of thermal effects.

II. NUMERICAL MODEL

The investigation of the tunability has been performed by use of a large signal model, that simulates transient behaviour of active as well as passive optical waveguides that include grating sections [4]. By dividing the device cavity into subsections, the longitudinal carrier and field distributions are taken into account. For a constant carrier density in each subsection, the field evolution can be found from solution of the mode

coupled partial differential equations [4]:

$$\left(\frac{\partial}{\partial z} \pm \left(j \frac{\Gamma}{2} \frac{\partial g}{\partial \omega} + \frac{1}{v_g} \right) \frac{\partial}{\partial t} \mp g \right) F^{\pm} = \mp \left(\kappa - \frac{\partial \kappa}{\partial \omega} \frac{\partial}{\partial t} \right) F^{\mp} e^{\pm 2j\delta_z} \quad (1)$$

Here F^+ and F^- are the forward and backward travelling fields, respectively. Γ is the confinement factor, g is the modal field gain, v_g is the group velocity, κ is the coupling coefficient and δ is the detuning of the real part of the wave number relative to the Bragg wave number.

Temperature variation of the modal gain, the loss, the modal refractive index, the carrier induced index change as well as the spontaneous recombination coefficients are taken into account. The temperature dependencies are implemented as first order Taylor expansions around a reference temperature. The temperature rise due to injection of the current I is found as a sum of the two terms $R_{th} \cdot V_j \cdot I$ and $C \cdot I^2$, representing the increase caused by Joule heating between the active layer and the heat sink, and the increase due to Joule heating in the upper layers of the laser structure, respectively [5]. R_{th} is the thermal resistance, V_j is the junction threshold voltage and C is given by

$$C = \frac{\rho_a d_a}{A} \left(\frac{d_a}{2K_a A} + R_{th} \right) + R_{th} \sum_i \frac{\rho_i d_i}{A} \quad (2)$$

d_a , ρ_a and K_a are thickness, ohmic resistivity and thermal conductivity of the active layer, while d_i and ρ_i are thickness and ohmic resistivity of the other layers of the device structure, respectively. A is the area through which current and heat are flowing. The transient thermal behaviour is accounted for by a thermal equivalent diagram containing R_{th} in parallel with a capacity C_{th} , yielding the time constant $\tau_{th} = R_{th} \cdot C_{th}$, which is taken as $0.5 \mu\text{s}$ in agreement with experimental results [6].

III. RESULTS AND DISCUSSION

We simulate a three-section DBR-laser characterised by the parameters given in Table I. For the case of no phase and Bragg section currents, the threshold level is $I_{th} = 28 \text{ mA}$. In all calculations, the gain section current is $2 \cdot I_{th}$, resulting in an output power of +2.1 dBm.

In DBR-lasers, the longitudinal mode closest to the Bragg wavelength normally oscillates. Consequently, the output wavelength can be tuned by changing the refractive index in the Bragg section by current injection, which leads to a change of the Bragg wavelength. Mode jumping occurs when

Manuscript received December 13, 1993; revised February 21, 1994.

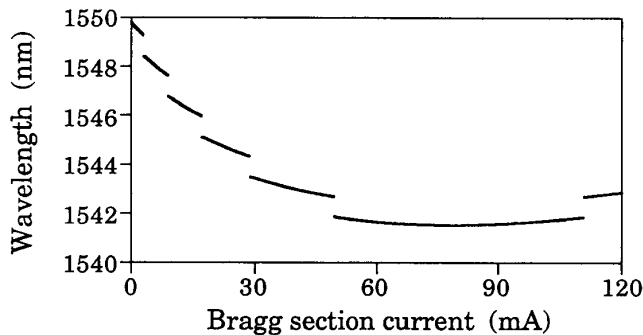
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IEEE Log Number 9401323.

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TABLE I
LIST OF PARAMETER VALUES

Parameter	Gain Section	Phase Section	Bragg Section
section length, μm	300	100	300
differential gain factor m^2	$300 \cdot 10^{-20}$	—	—
confinement factor	0.31	0.53	0.53
internal loss, m^{-1}	$3.00 \cdot 10^3$	$3.00 \cdot 10^3$	$4.00 \cdot 10^3$
wave guide thickness, μm	0.15	0.30	0.30
waveguide width, μm	2.00	2.00	2.00
reference refractive index	3.25	3.20	3.20
corrugation period, m	—	—	$2.42 \cdot 10^{-7}$
coupling coefficient, m^{-1}	—	—	$3.30 \cdot 10^3$
recombination coefficient, s^{-1}	$1.50 \cdot 10^8$	$1.68 \cdot 10^8$	$1.68 \cdot 10^8$
recombination coefficient, m^3s^{-1}	$4.00 \cdot 10^{-16}$	$0.28 \cdot 10^{-16}$	$0.28 \cdot 10^{-16}$
recombination coefficient, m^6s^{-1}	$5.00 \cdot 10^{-41}$	$5.24 \cdot 10^{-42}$	$5.24 \cdot 10^{-42}$
thermal resistance, KW^{-1}	90.00	40.00	40.00
junction threshold voltage, V	0.83	0.95	0.95
thermal conductivity, W(Km)^{-1}	4.50	4.50	4.50

Fig. 1. Calculated output wavelength versus Bragg section current. The waveguide thickness in the Bragg section is $0.3 \mu\text{m}$.

the peak of the Bragg reflection is tuned over adjacent modes as seen in Fig. 1, that shows output wavelength versus Bragg section current. Due to thermal effects, the maximum tuning range is limited to 7.5 nm for a Bragg section current of 80 mA. Higher current results in an increasing output wavelength for increasing Bragg section current.

Simulations of transient time responses are shown in Fig. 2 for wavelength switching over 5 modes ($\sim 6.5 \text{ nm}$). The switching time in case of decreasing wavelength is approximately 6 ns while it is almost 10 ns for increasing wavelength due to a longer carrier lifetime. Fig. 2 also indicates the influence of the transient thermal effect, that leads to a slowly drifting wavelength opposite the switching direction. The steady state output wavelength's reached after a few μs are indicated with arrows. For application in WDM-systems with narrow channel spacings, this thermal wavelength drifting has to be compensated for [7].

In order to minimise the wavelength switching time, the effective carrier lifetime in the Bragg section should be short, which requires a high carrier concentration [8]. This is verified in Fig. 3, showing the switching time versus initial Bragg

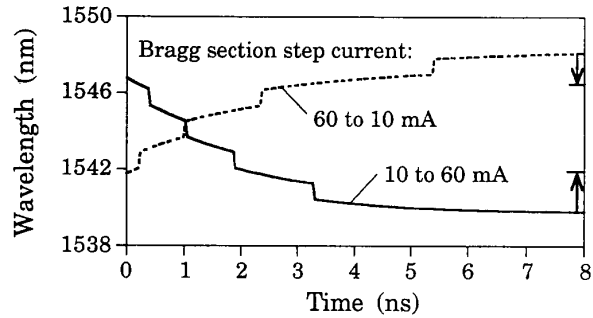
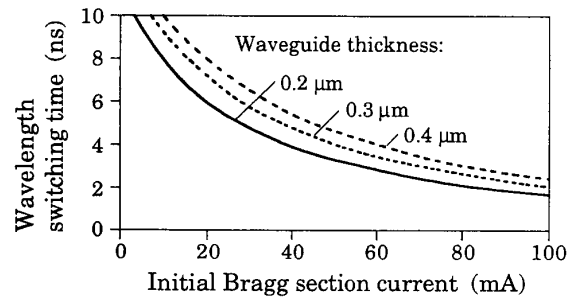
Fig. 2. Dynamic response for step modulation of the Bragg section current. Arrows indicate the steady state wavelength's reached after a few μs due to thermal effects. The waveguide thickness in the Bragg section is $0.3 \mu\text{m}$.

Fig. 3. Calculated wavelength switching time versus initial Bragg section current for injection of a 20 mA step pulse. The waveguide thickness in the Bragg section is parameter.

section current for a 20 mA step current modulation. The waveguide thickness in the Bragg section is parameter. The calculation shows significantly decreasing switching times from more than 10 ns to 2 ns for increasing current. It is also seen, that the switching time is reduced by decreasing the waveguide thickness in the Bragg section.

The output wavelength can be adjusted continuously within a mode spacing by changing the phase section current as shown in Fig. 4. For increasing current, the oscillating wavelength repeatedly jumps among the adjacent modes around the Bragg wavelength of 1549.9 nm (Bragg section current = 0). The modes shift toward shorter wavelength's for increasing current because of a decreasing refractive index. However, for phase section currents exceeding 54 mA, thermal effects will be dominating and induce an increasing index with current, resulting in mode drifting towards higher wavelength's.

By modulation of the phase section current, a trade off exists between short switching times and small influences of thermal effects. This is illustrated in Fig. 5, showing the wavelength change versus time in case of step modulation of the phase section current for three different current steps; all producing the same wavelength change of 0.48 nm without mode hopping. The fastest switching time of 2 ns is predicted for a current step from 40 to 60 mA, followed by 4 ns and approximately 9 ns for step currents from 15 to 21 mA and from 6 to 10 mA, respectively. However, the calculation also indicates the steady state output wavelength's, reached after approximately 3 μs due to the temperature rise. No significant

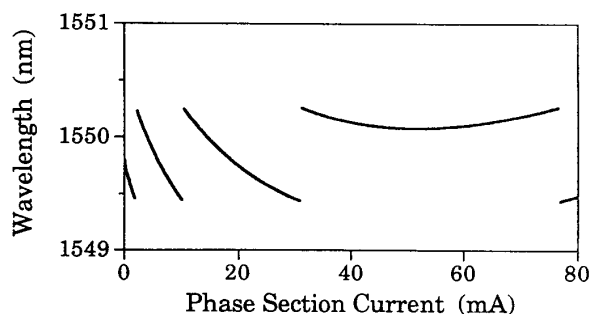


Fig. 4. Calculated output wavelength versus phase section current.

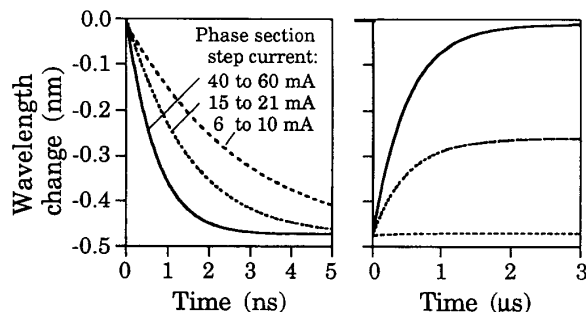


Fig. 5. Change of output wavelength versus time for step modulation of the phase section current.

thermal drift is observed for the 6 to 10 mA step pulse, while in case of the 40 to 60 mA step current, the output wavelength nearly drifts back to its initial value.

IV. CONCLUSION

The static and transient wavelength tunability of DBR-lasers are investigated by use of a detailed dynamic model.

Wavelength tuning with switching times from 0.5 to more than 10 ns is predicted, dependent on the bias condition. Due to a short effective carrier lifetime in the tuning section, fast switching times are a consequence of high current injection, which, however, increases the influence of thermal effects. Therefore, an optimum control of the device depends on the requirements to the switching speed for the particular application of the laser, since there is a trade off between ultra fast wavelength switching and thermal stability.

It is also shown that the switching times are reduced by decreasing the waveguide dimensions in the Bragg section of the DBR-laser, and the calculations establish, that the limitation in tuning range is induced by thermal effects.

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